

# An Update on Science Studies for the Electron Ion Collider

*Thomas Ullrich*

July 8, 2008

RHIC S&T Review 7-9 July 2008

# EIC: Study of Glue That Binds Us All

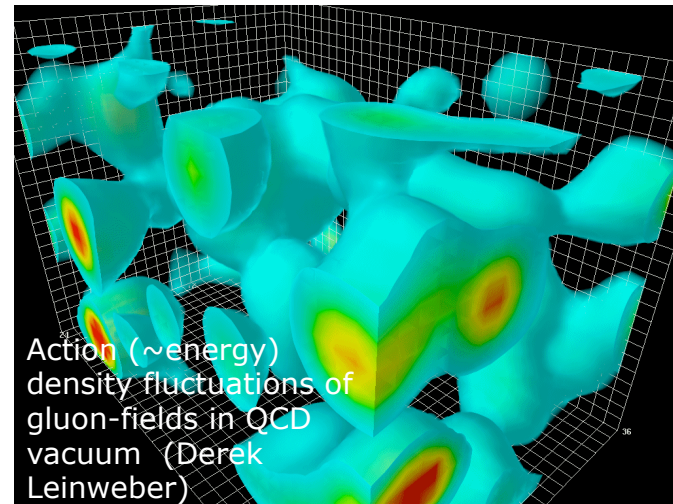
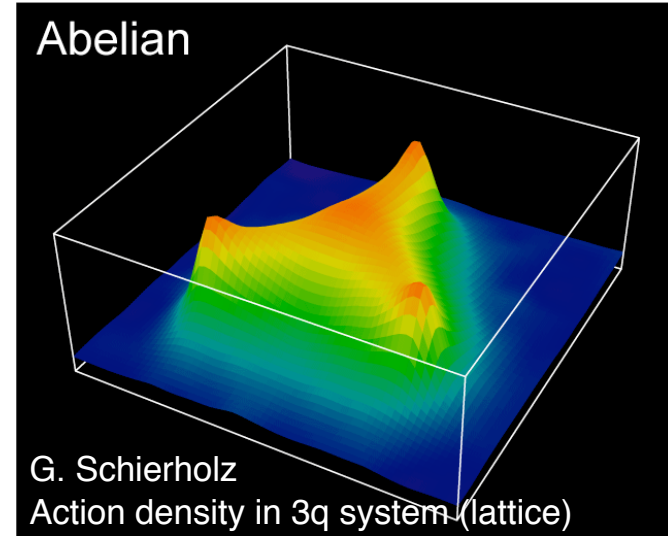
$$L_{QCD} = \bar{q}(i\gamma^\mu \partial_\mu - m)q - g(\bar{q}\gamma^\mu T_a q)A_\mu^a - \frac{1}{4}G_{\mu\nu}^a G_a^{\mu\nu}$$

- **Gluons**

- ▶ Self-interacting force carries
- ▶ Determine essential features of QCD
- ▶ Dominate structure of QCD vacuum
- ▶ Responsible for >95% of visible mass in universe

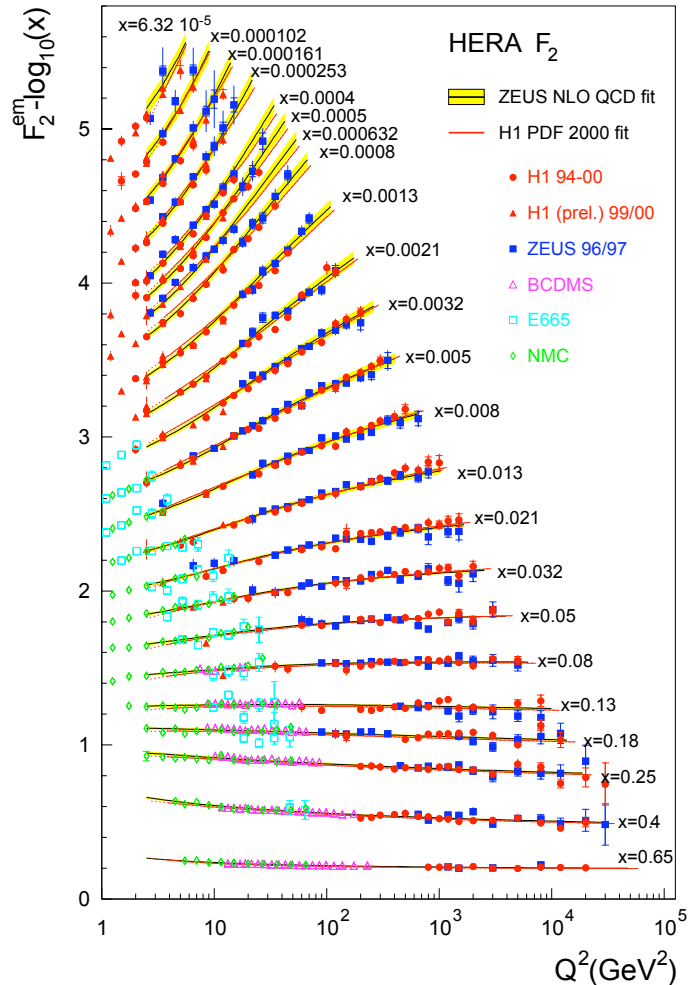
Despite this dominance, the properties of gluons in matter remain largely unexplored

⇒ Electron Ion Collider = EIC

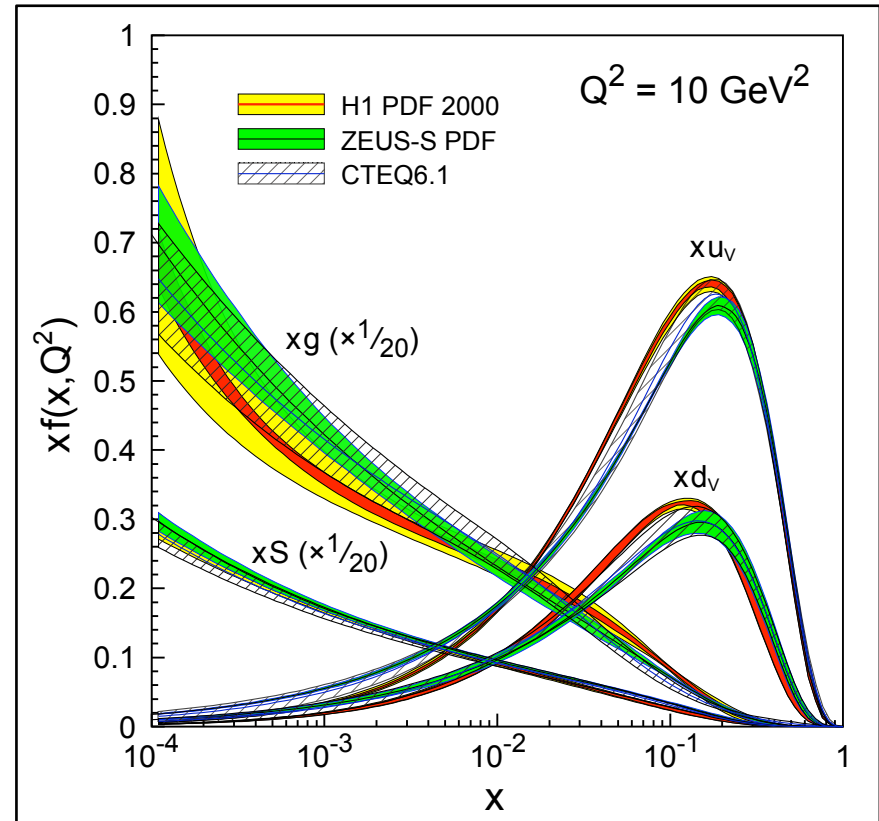


# How Glue is Measured (so far)

$$\frac{d^2\sigma^{ep\rightarrow eX}}{dx dQ^2} = \frac{4\pi\alpha_{e.m.}^2}{xQ^4} \left[ \left(1 - y + \frac{y^2}{2}\right) F_2(x, Q^2) - \frac{y^2}{2} F_L(x, Q^2) \right]$$

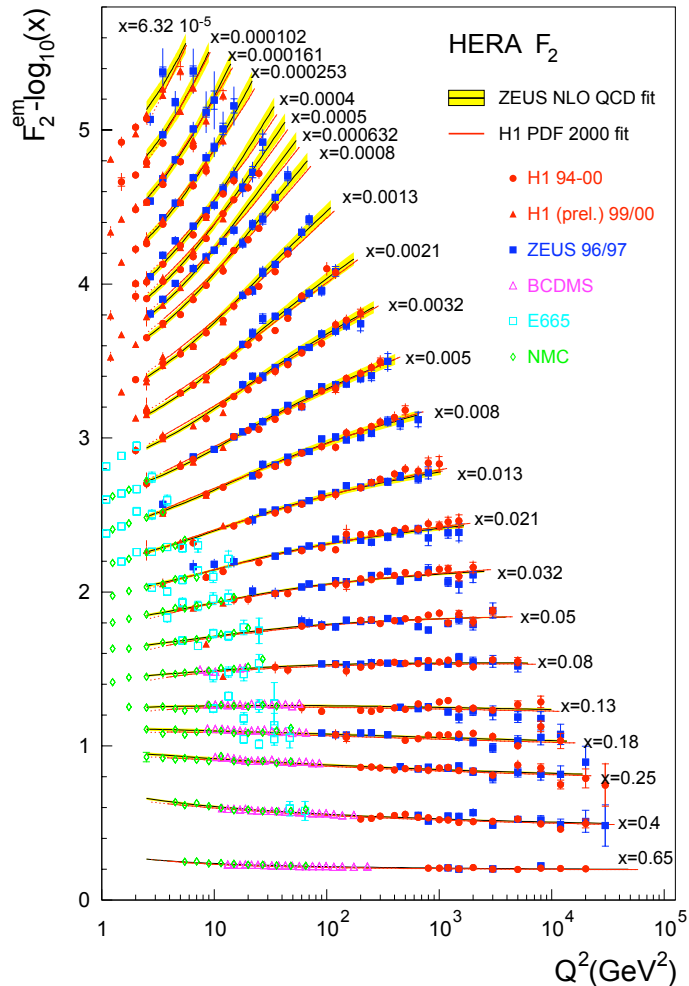


Scaling violation:  $dF_2/d\ln Q^2$  and linear DGLAP Evolution  $\Rightarrow G(x, Q^2)$

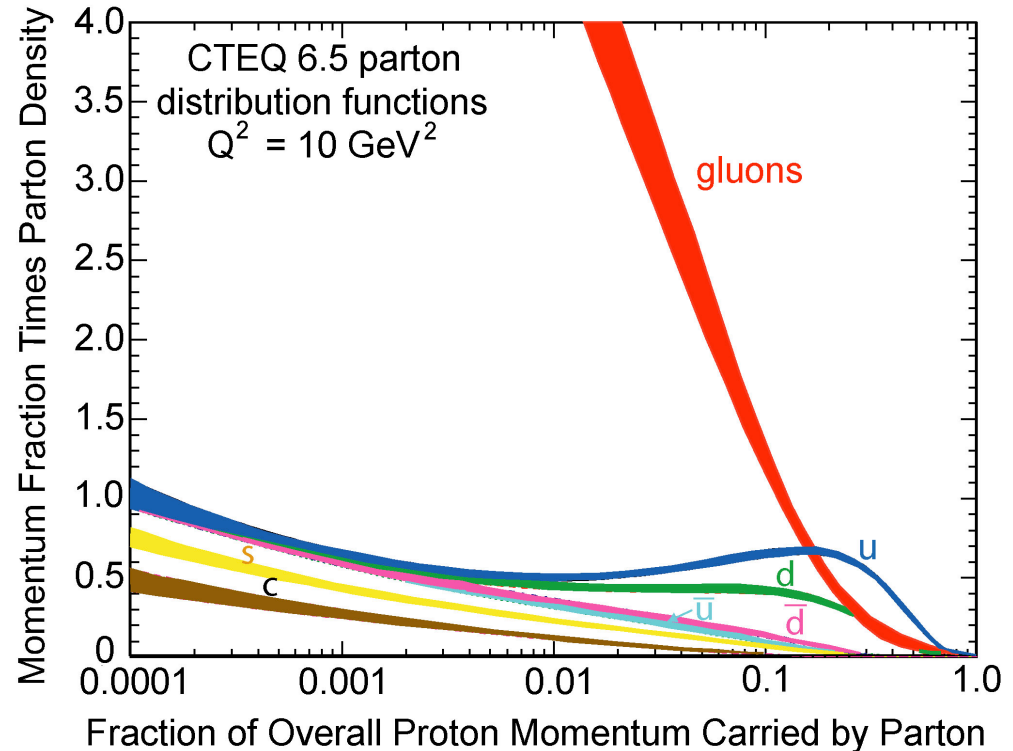


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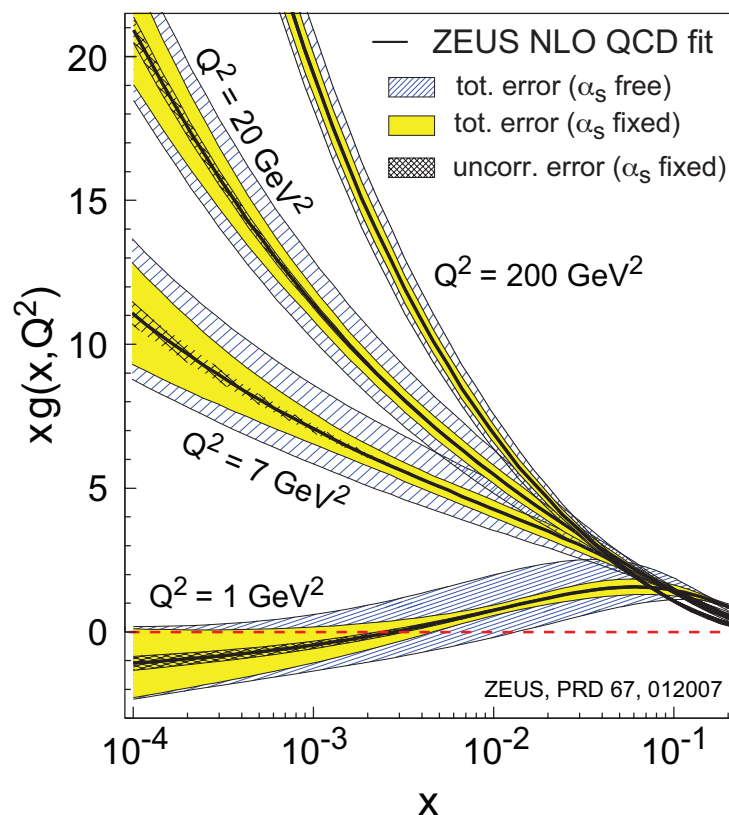
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# What Do We Know About Glue?



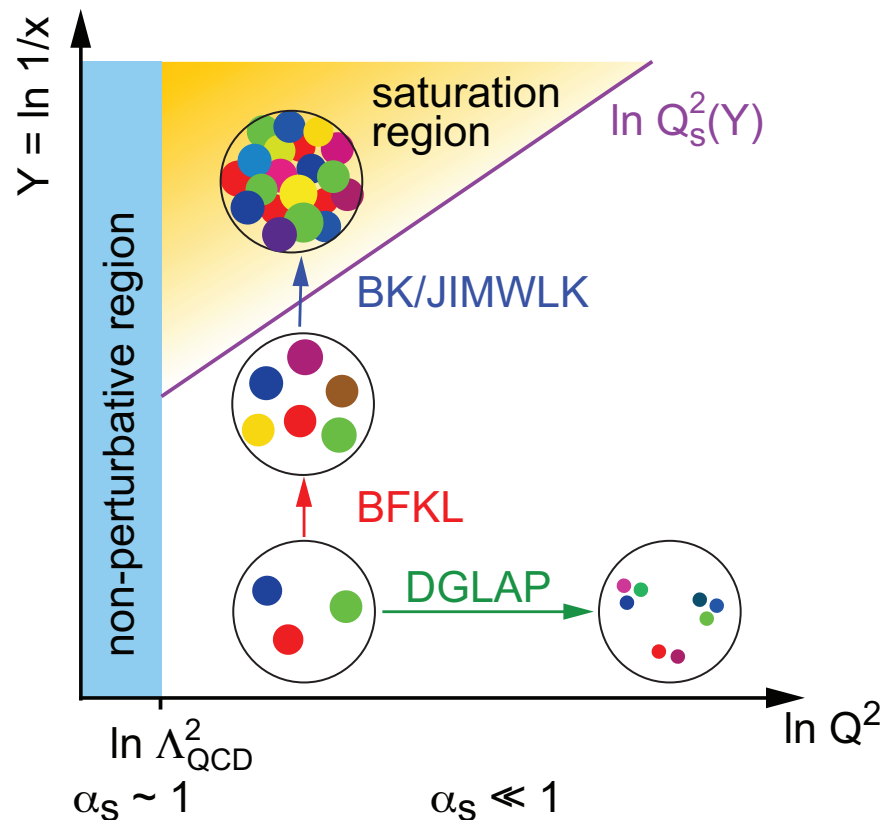
## Linear DGLAP evolution

negative  $G(x, Q^2)$  at low  $Q^2$  ?

built in high energy “catastrophe”

-  $xG$  rapid rise violates unitary bound

$xG$  **must** saturate  $\Rightarrow$  new approach



## BK/JIMWLK: *non-linear* effects $\Rightarrow$ saturation

- characterized by  $Q_s(x, A)$
- believed to have properties of a *Color Glass Condensate*

# The Science Program of an EIC

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**EIC research will penetrate some of the most profound mysteries of questions of 21st century physics**

- **Explore new QCD frontier: strong color fields in nuclei**
  - ▶ How do the gluons contribute to the structure of the nucleus?
  - ▶ What are the properties of high density gluon *matter*?
  - ▶ How do fast quarks or gluons interact as they traverse nuclear matter?
- **Precisely image sea-quarks and gluons in the nucleon**
  - ▶ How do the gluons and sea-quarks contribute to the spin structure of the nucleon?
  - ▶ What is the spatial distribution of the gluons and sea quarks in the nucleon?
  - ▶ How do hadronic final-states form in QCD?

# EIC WG Organization Chart

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Overall: 96+ Scientists, 28 Institutions, 9 countries

## **EICC Steering Committee**

- Antje Bruell, Jlab
- Abhay Deshpande\*, Stony Brook, RBRC
- Rolf Ent, Jlab
- Charles Hyde, ODU/UBP, France
- Peter Jacobs, LBL
- Richard Milner\*, MIT
- Thomas Ulrich, BNL
- Raju Venugopalan, BNL
- Werner Vogelsang, BNL

\* *contact persons*

## **International Advisory Committee**

- Jochen Bartels (DESY)
- Allen Caldwell (MPI, Munich)
- Albert De Roeck (CERN)
- Walter Henning (ANL)
- Dave Hertzog (UIUC)
- Xiangdong Ji (U. Maryland)
- Robert Klanner (U. Hamburg)
- Katsunobu Oide (KEK)
- Naohito Saito (KEK)
- Uli Wienands (SLAC)

## Working Groups:

### **ep Physics**

- Antje Bruell, JLAB
- Ernst Sichterman, LBL
- Werner Vogelsang, BNL
- Christian Weiss, JLAB

### **eA Physics**

- Vadim Guzey, JLAB
- Dave Morrison, BNL
- Thomas Ullrich, BNL
- Raju Venugopalan, BNL

### **Detector**

- Elke Aschenauer, JLAB
  - Edward Kinney, Colorado
  - Andy Miller, TRIUMF
  - Bernd Surrow, MIT
- ### **Electron Beam Polarimetry**
- Wolfgang Lorenzon, Michigan

**2 collaboration meetings/year;**

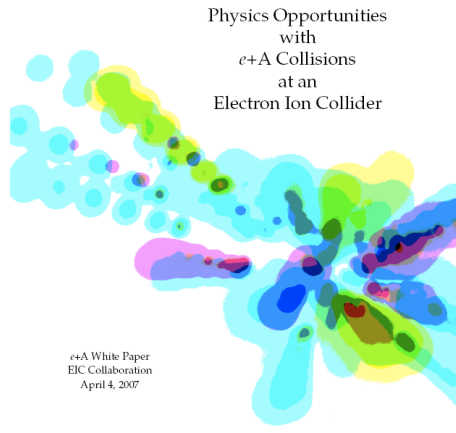
**steering committee meets once a month; regular WG meetings**

# EIC in 2007 - a good year

## A High Luminosity, High Energy Electron-Ion Collider

*A New Experimental Quest to Study the Glue  
That Binds Us All*

The Electron Ion Collider Working Group  
April 24, 2007



## Documenting the Science Case

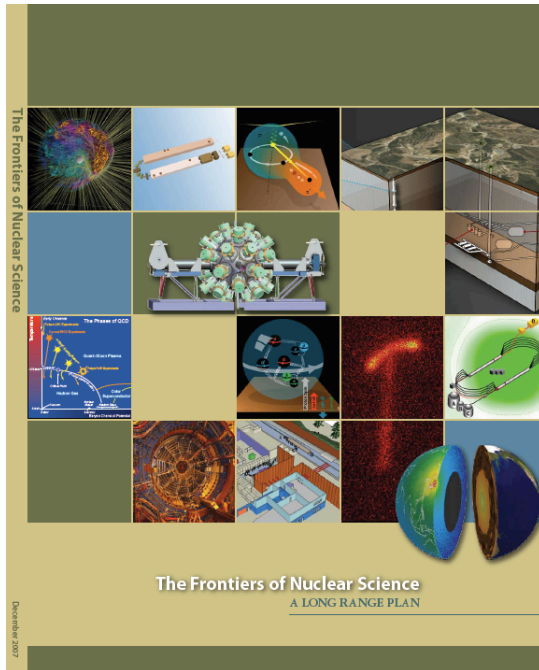
- The Electron Ion Collider (EIC) White Paper
- The GPD/DVCS White Paper
- Position Paper:  $e+A$  Physics at an Electron Ion Collider

## NSAC Long Range Plan 2007

“An **Electron-Ion Collider** (EIC) with polarized beams has been **embraced by the U.S. nuclear science community** as embodying the vision for reaching the next **QCD frontier**.”

### NSAC Recommendation for EIC:

“We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a **polarized Electron-Ion Collider**.”



# Current Science Studies: e+A

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Key Physics Studies and their implications on detector and machine requirements

## The Nuclear Oomph

- physics reach into saturation regime  $\Rightarrow$  machine

## Momentum Distribution of Gluons $G(x, Q^2)$ :

- via scaling violation of  $F_2$
- directly via  $F_L$  ( $\sim G(x, Q^2)$ )
- through 2+1 jets
- through diffractive events ( $\sim G(x, Q^2)^2$ )

## Diffractive Physics

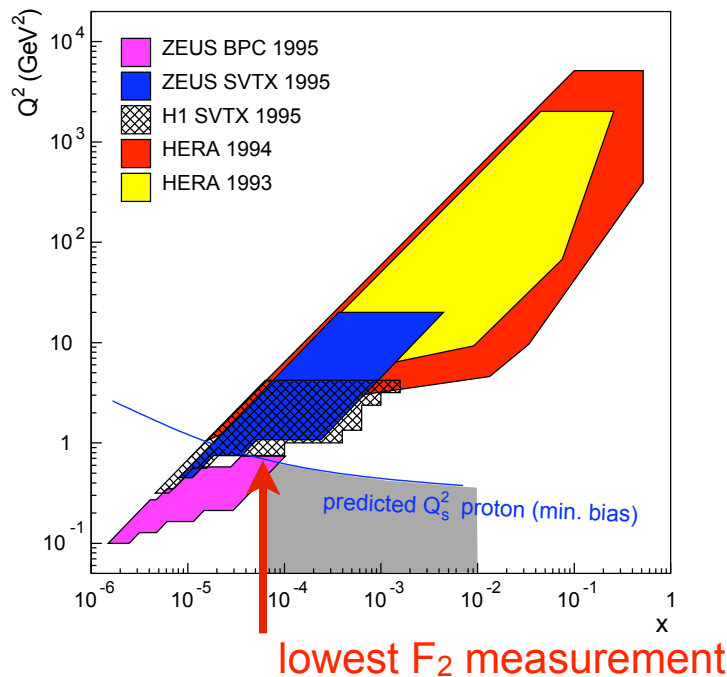
- Tagging diffractive events in e+A  $\Rightarrow$  feasibility & detector
- Measuring diffractive events  $\Rightarrow$  detector

# Nuclear Oomph

HERA e+p:

Despite energy and low-x reach higher than EIC:

no clear evidence for non-linear QCD effects (saturation phenomena)



e+A @ EIC:

Probes interact over distances  $L \sim 1/(2m_N x)$

For  $L > 2 R_A \sim A^{1/3}$  probe interacts

*coherently* with all nucleons

Nuclear Enhancement  
(Oomph):

$$(Q_s^A)^2 \approx c Q_0^2 \left( \frac{A}{x} \right)^{1/3}$$

Enhancement of  $Q_s$  with  $A \Rightarrow$  non-linear QCD regime reached at significantly larger  $x$  (lower  $\sqrt{s}$ ) in  $A$  than in proton

**e+A physics program relies on this nuclear enhancement**

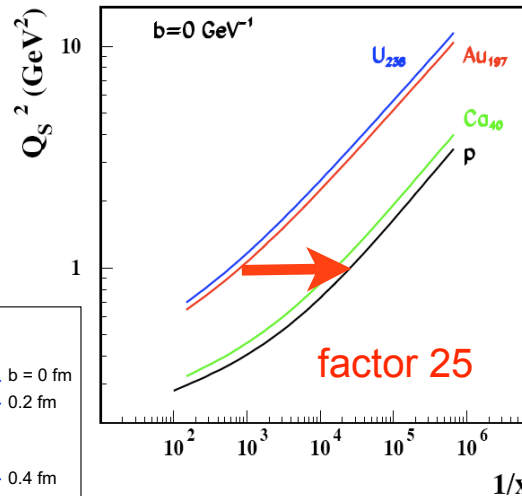
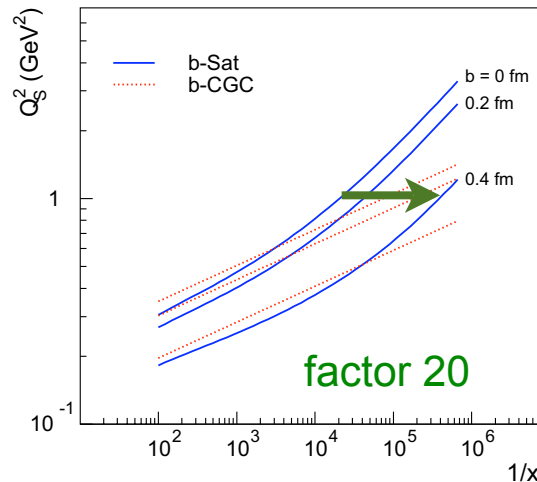
# Recent Studies on Nuclear Enhancement

Kowalski, Lappi and Venugopalan, PRL 100, 022303 (2008)

More detailed state-of-the-art analysis:

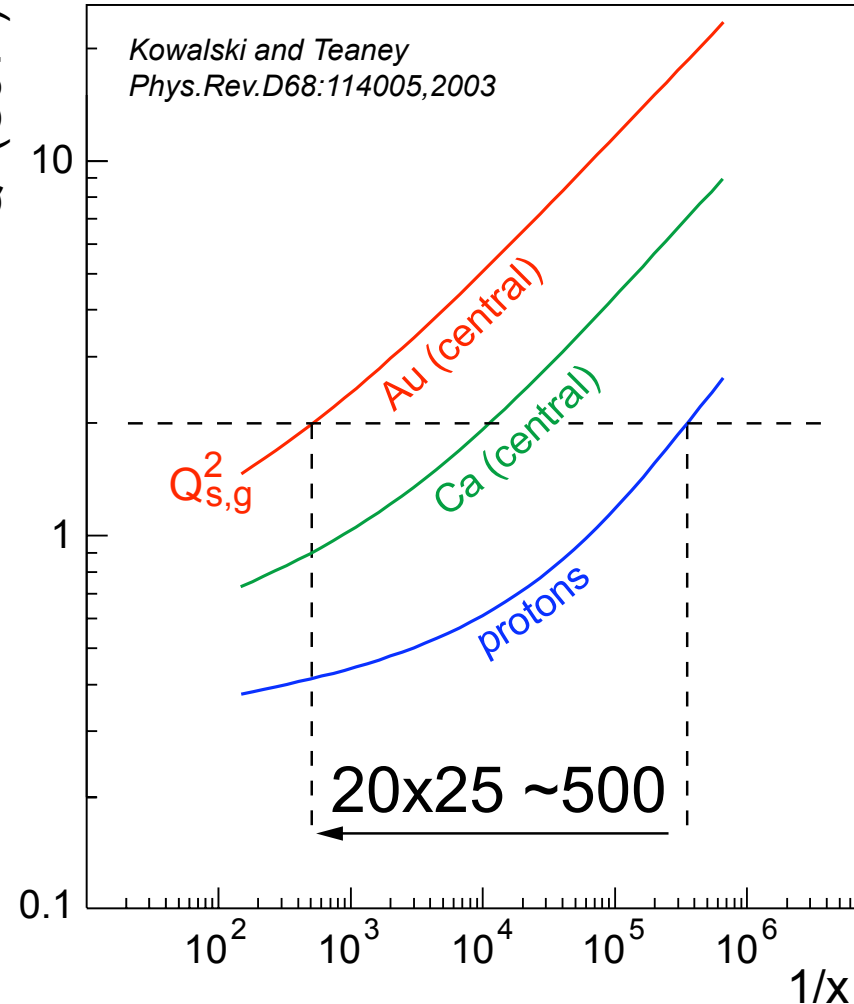
Using dipole model and extracting  $b$  and  $x$  dependence of  $Q_s$  from fits to diffractive and exclusive HERA data  
 $\Rightarrow$  construct  $b$  dependent  $Q_s(x, b)$   
 in the nuclei

Confirm pocket formula  $\sim A^{1/3}$ :



$b$ -dependence

$Q^2$  (GeV<sup>2</sup>)

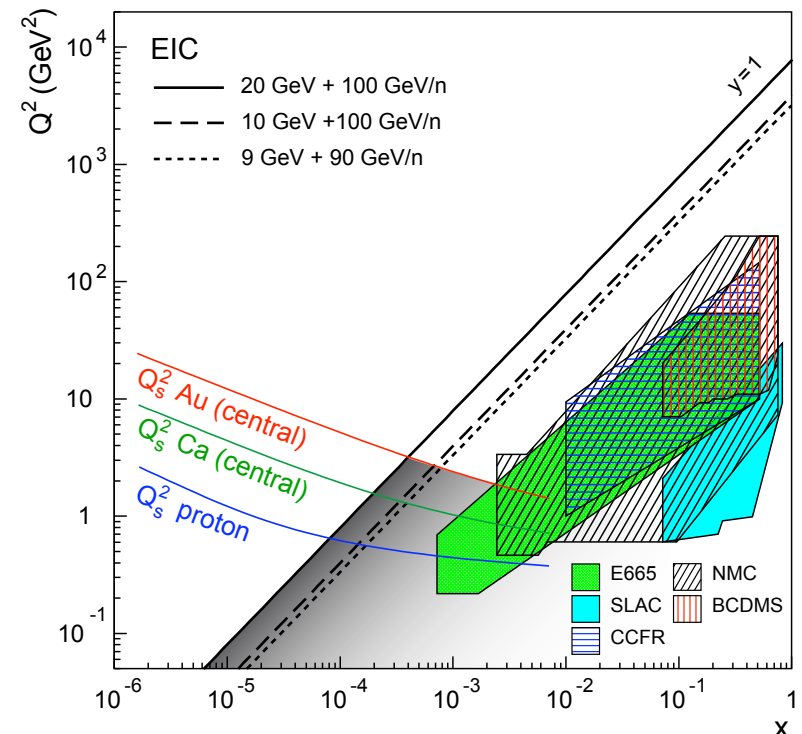
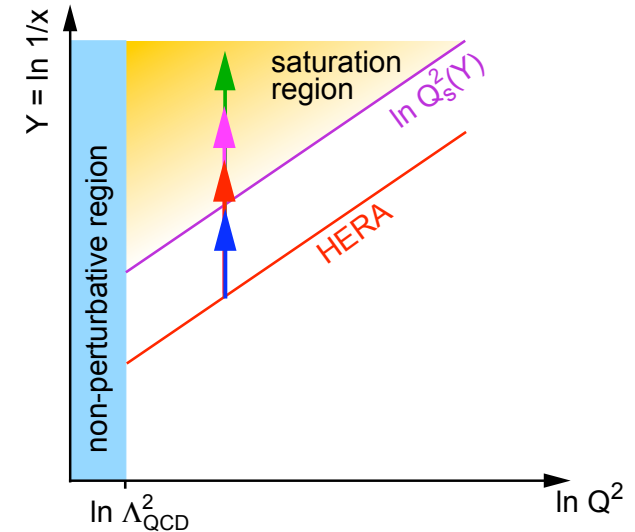


# Implication for Machine Requirements

EIC Beam Energy (GeV)	$\sqrt{s}$ (GeV)	low-x reach compared to HERA (e+p equivalent)
2+100	28	4
10+100	63	18
20+100	89	36
20+130	102	50
30+130	125	71

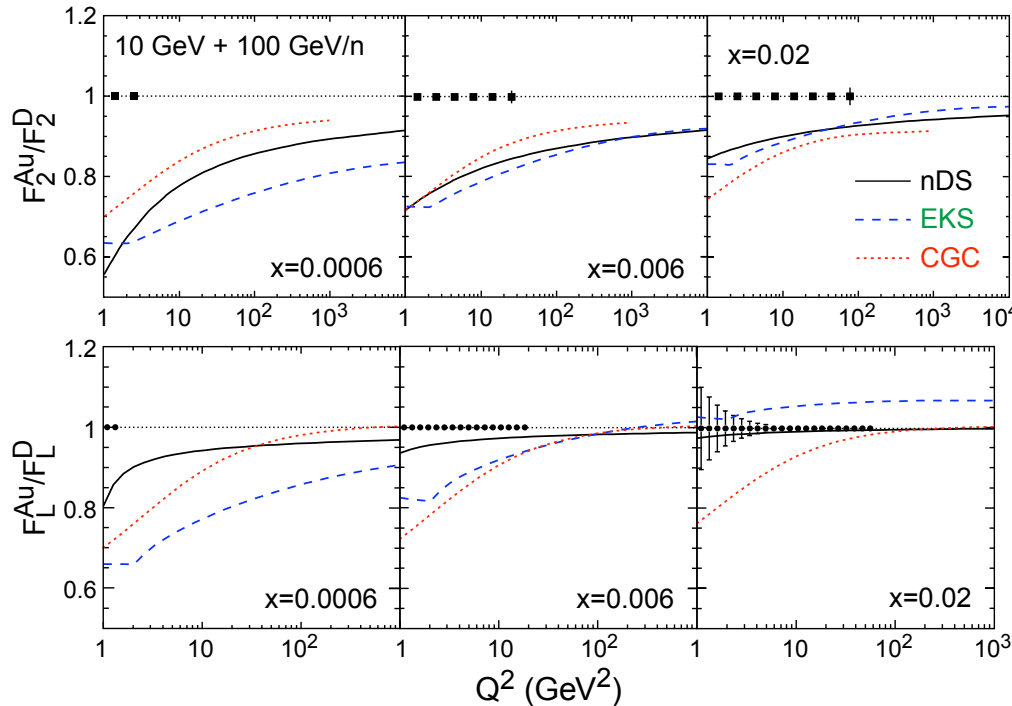
Despite advanced theory:

- We do not know for sure how far HERA was away from the saturation physics regime
- We have to reach far into this regime and we need a safety margin:
- $\sqrt{s} \gtrsim 63$  GeV

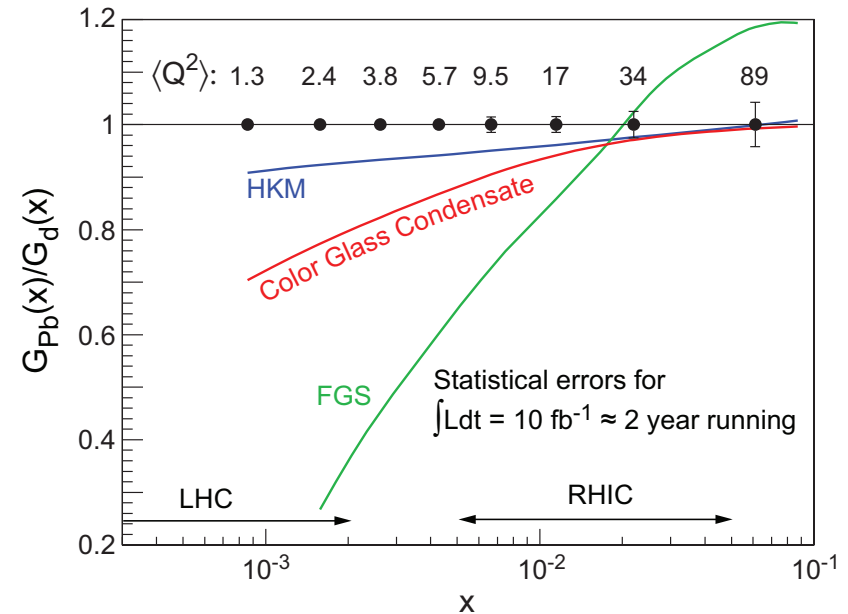


# Key Measurement: $F_2, F_L \Rightarrow G(x, Q^2)$

Simulations to demonstrate the quality of EIC measurements



Folded with EIC acceptance



Assume:

$L = 3.8 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  (100x Hera)

$T = 10$  weeks

duty cycle: 50%

$L \sim 1/A$  (approx)

$\int L dt = 11 \text{ fb}^{-1}$

$F_L \sim \alpha_s G(x, Q^2)$  requires  $\sqrt{s}$  scan,  $Q^2/xs = y$

Plots above:

$\int \mathcal{L} dt = 4/A \text{ fb}^{-1}$  (10+100) GeV

$= 4/A \text{ fb}^{-1}$  (10+50) GeV

$= 2/A \text{ fb}^{-1}$  (5+50) GeV

statistical error only

# $G(x, Q^2)$ and Systematic Errors

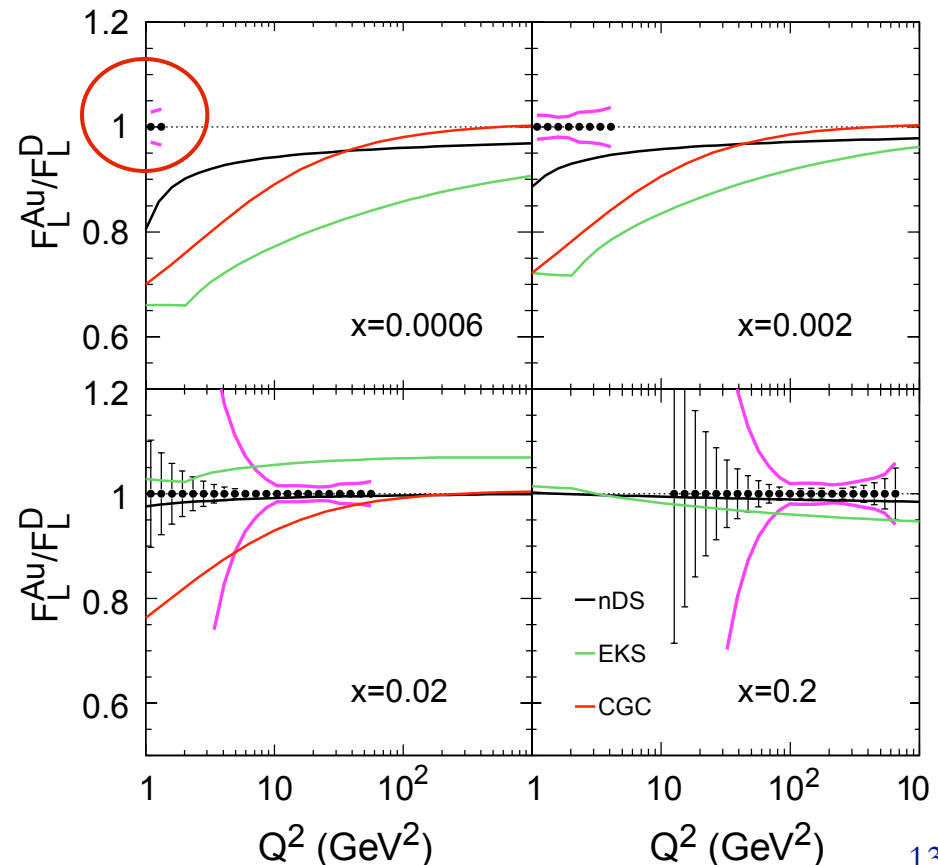
## Systematic Uncertainties

- While statistical errors can be rather well evaluated (acceptance, kinematics, L) the systematic uncertainties are the big unknown
- Hard to estimate: need at least a rough detector design

This study:  
1% energy-to-energy normalization  
(typical HERA values)

Systematic uncertainties  
exceed  
statistical errors

- We probably can do better (conceptual design!)



# Current Focus: Diffractive Events

Surprising Discovery at HERA ep:

15% of all e+p events are hard diffractive (p intact)

Diffractive cross-section  $\sigma_{\text{diff}}/\sigma_{\text{tot}}$  in e+A: 25-40%?

Look inside the “Pomeron”: diffractive structure functions  $F_2^D$ ,  $F_L^D$

Diffractive vector meson production  $\sim G(x, Q^2)^2$

## “Footprint” of Diffraction

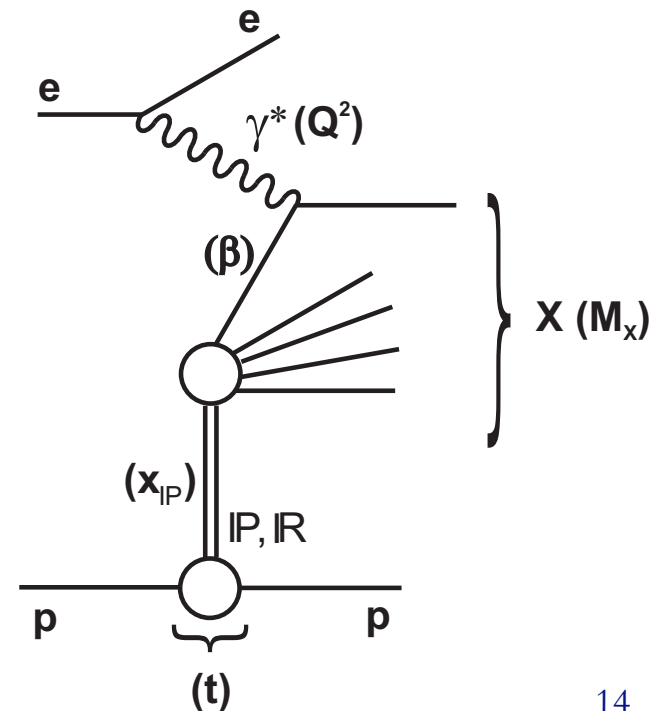
1. Outgoing proton with large  $x_L = E_{p'}/E_p \approx 1$

- ▶ typical  $t = (p-p')^2$  smaller than  $1 \text{ GeV}^2$ ,  
 $\langle t \rangle \approx 0.15 \text{ GeV}^2$

2. Produced system  $X$  must have small mass w.r.t  $\gamma^*p$  center-of-mass ( $W$ )

3. Rapidity gap between  $p$  and  $X$

- ▶  $\Delta\eta \approx \ln(1/x_{IP})$



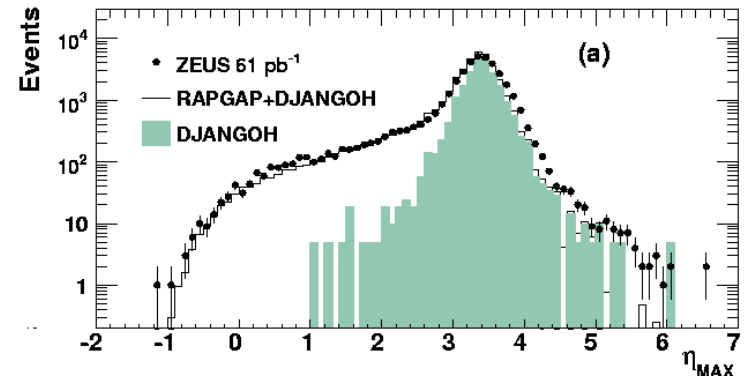
# Identifying Diffractive Events

## Large rapidity gap method

- ▶ no information on  $t$  (limited  $X_{IP}$  reach)

## Proton Spectrometer

- Identify leading proton
  - ▶ low  $t \Rightarrow$  outgoing p scattered at low angles close to the beam axis ( $\theta \lesssim 1$  mrad)
  - ▶ Roman pots w Si-position detectors + beam optics
  - ▶ RHIC experience from pp2pp program



## Challenge: Nuclei break up easily (compared to p)

Diffractive eA event	{	$A \rightarrow$ fragments (breakup)	challenging!
		$A \rightarrow n + A-1$ (Dipole Resonance)	possible ?!
		$A$ stays intact and $\theta > 0.1$ mrad ( $P=?$ )	best case

Current efforts: Estimate:  $P_{\text{breakup}}$ ,  $P_{\text{non-breakup}}$ ,  $P_{\text{n-emission}}$

A-Spectrometer concept (beamline integration)

Experience at RHIC from UPC program

# Current Science Studies: e+p

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While there's lots of interesting e+p physics that does not need polarized electron and protons, it's the polarized e+p program that constitutes a new energy frontier

## Inclusive physics

- unpolarized + polarized structure functions

## Direct measurements of polarized gluon distribution $\Delta G$

- current studies: via charm production

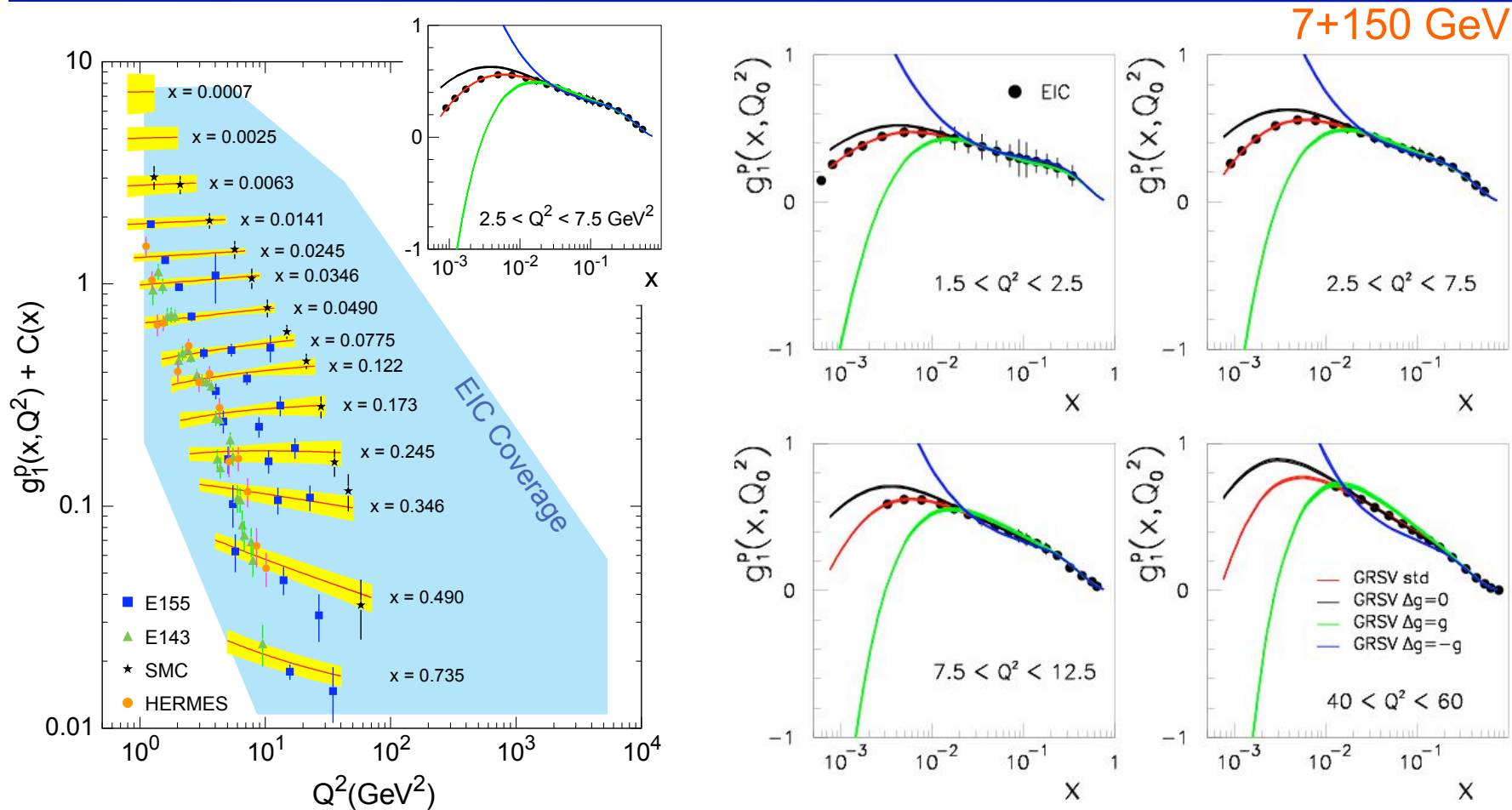
## Semi-inclusive physics

- current quark fragmentation and flavor separation
- $p_T$  dependent parton distributions
- Sivers and Collins functions

## Exclusive processes and diffraction

- DVCS + meson production (pseudoscalar and vector)
- 3 dimensional image of the proton & orbital momentum
- General Parton Distributions (GPD)

# Spin structure functions: $g_1(x, Q^2)$



$x, Q^2$  reach appears sufficient at  $\sqrt{s}=100$  GeV to distinguish models for  $g_1$  in a crucial  $x$  range as long as  $Q^2 < 12$   $\text{GeV}^2$

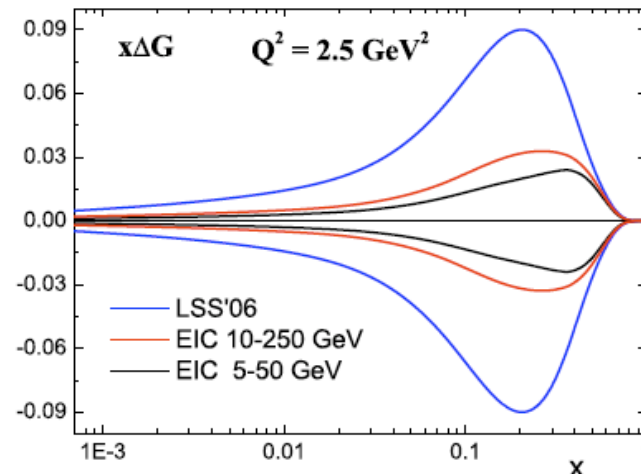
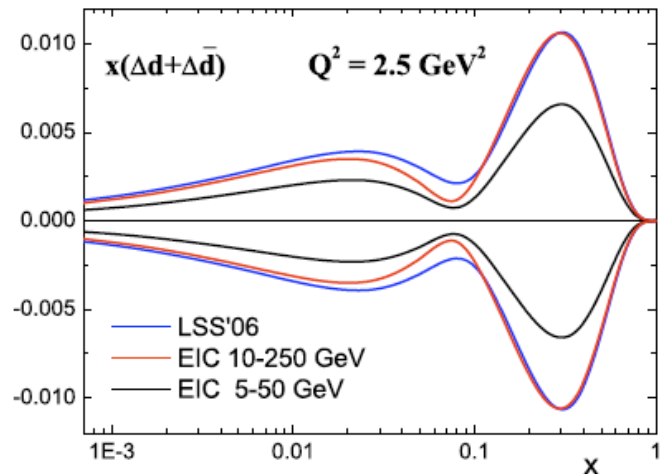
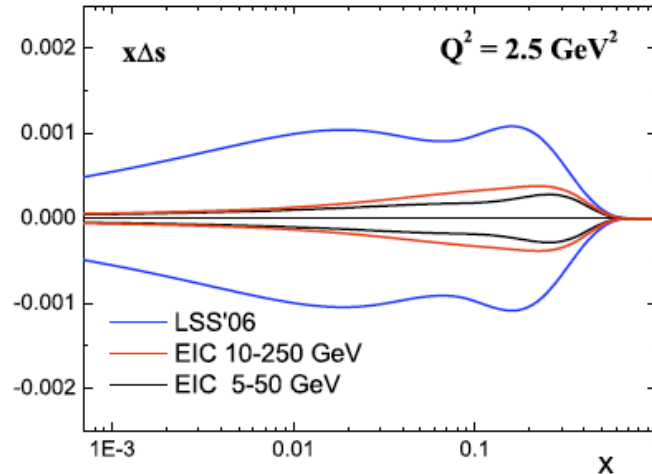
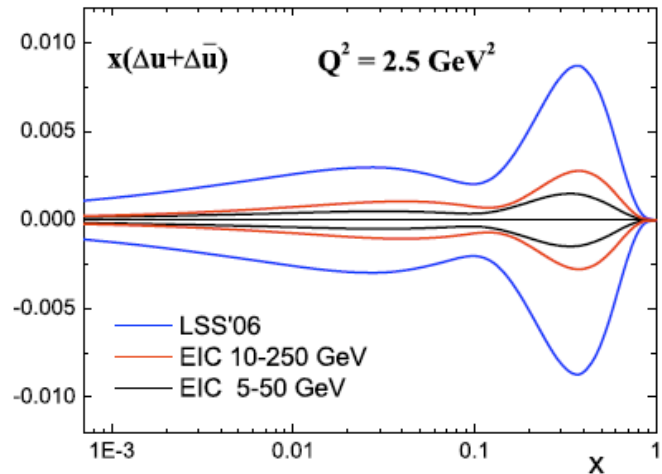
Measurement of  $g_1$  at very small  $x$  could settle the  $\Delta G$  problem.

20/30+325 GeV (eRHIC) option gets you up to  $Q^2=40$   $\text{GeV}^2$  at  $x=10^{-3}$

# Inclusive Scattering

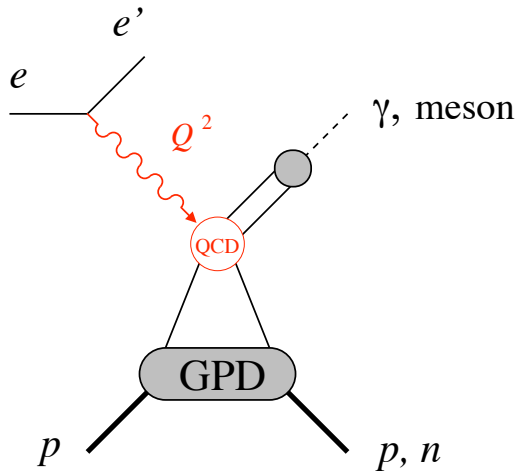
## Impact on EIC on the uncertainties for NLO polarized PDFs

$q(x, Q^2)$ ,  $G(x, Q^2)$  are (anti) quark and gluon polarized densities

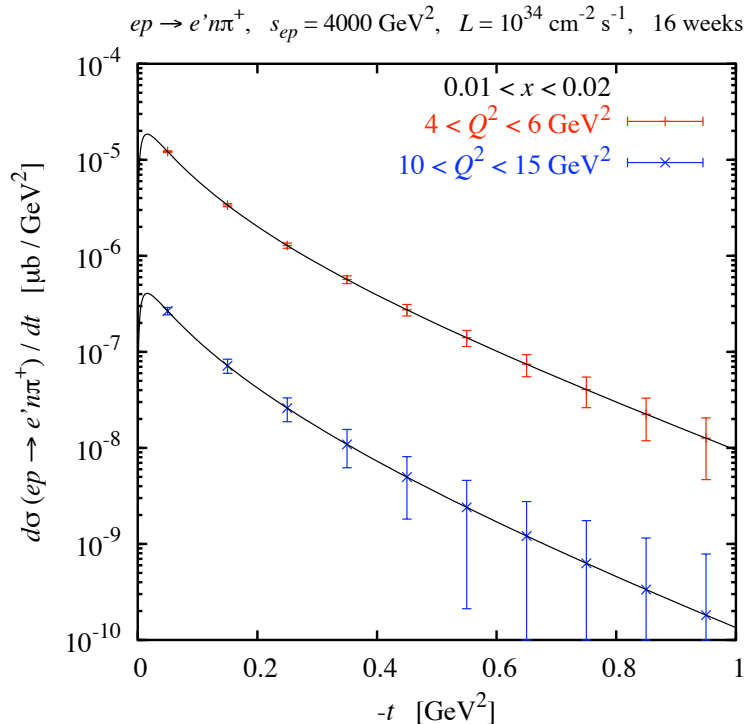


(LSS'06  
derived from  
recent CLAS  
and Compass  
data)

# Exclusive Processes in $e+p$



- Essential part of the EIC program
  - ▶ General Parton Distributions (GPD)
  - ▶ “Quark/gluon imaging” of nucleon
- Challenging measurement
  - ▶ High luminosity  $L \sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
  - ▶ Detectors: coverage, resolution, particle ID
- Lessons from MC simulations
  - ▶  $e+p \rightarrow e' \pi^+ n, \pi^0 p, K\Lambda$



A. Bruell, T. Horn, G. Huber,  
C. Weiss (2008)

# Summary

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## Ongoing physics studies

- Current focus e+A
  - ▶ diffractive physics & detector requirements
  - ▶ next: jet physics
- Current focus e+p
  - ▶ exclusive processes (luminosity requirements)
  - ▶ various processes: kinematics & detector requirements

## All studies & efforts still conducted by few enthusiasts

- Relatively broad interest but many are reluctant to get further involved at this point
- Most efforts centered around labs (BNL, JLAB, LBNL)
- Need to strengthen the user base that is willing to get their hand dirty

# EIC Roadmap

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## NSAC Long Range Plan 2007

- ▶ Recommendation: \$6M/year for 5 years for machine and detector R&D

## Goal for Next Long Range Plan ~2012

- ▶ High-level (top) recommendation for construction

## EIC Roadmap (Technology Driven)

- |   |      |
|---|------|
| ▶ Finalize Detector Requirements from Physics   | 2008 |
| ▶ Revised/Initial Cost Estimates for eRHIC/ELIC | 2008 |
| ▶ Investigate Potential Cost Reductions         | 2009 |
| ▶ Establish process for EIC design decision     | 2010 |
| ▶ Conceptual detector designs                   | 2010 |
| ▶ R&D to guide EIC design decision              | 2011 |
| ▶ EIC design decision                           | 2011 |
| ▶ MOU's with foreign countries?                 | 2012 |

Continuous effort: Strengthening the science case